Spectral anisothermality: A two-look approach to thermal infrared data analysis of planetary basaltic surfaces. B. E. McKeeby, M. S. Ramsey . Department of Geology and Environmental Science, University of Pittsburgh, 4107 O'Hara Street SRCC, Pittsburgh, PA, 15260 (bem101@pitt.edu)

Introduction: Quantitative measurements of surface roughness are critical to many aspects of planetary science, including geological and geomorphological studies, volcanological evolution, compositional analysis, and potential future landing site selections [1]. Surface roughness characterization is primarily limited by the wavelength range and spatial resolution of the data. On planetary surfaces, roughness below the spatial resolution of the data produces temperature heterogeneities that alter the spectral morphology of thermal infrared (TIR) emission spectra [1,2,3]. These heterogeneities produce a negative slope toward longer wavelengths upon emissivity temperature separation which adversely impacts subsequent compositional analysis. This slope affect is perhaps most apparent in emission data from very rough extrusive volcanic surfaces. The higher effusion rates combined with the pre-existing topography can emplace lavas with a large range of surface roughness (similar to that of ‘a’a basaltic textures on Earth). The degree of this anisothermal effect on the emission spectrum of any given pixel is directly proportional to the degree and distribution of local topographic slopes in that pixel, which is a function of the spatial resolution of the instrument [2,3].

Work by Bandfield (2009) and Bandfield and Edwards (2008) demonstrated that TIR spectral slopes can be used to quantitatively characterize subpixel surface roughness. This was done by modeling Thermal Emission Spectrometer (TES) emission phase function data using the KRC model [4] and the ϴ-bar parameter in Hapke Theory [5]. Furthermore, in addition to anisothermal surfaces, increases in the viewing angle from nadir also affects the measured emissivity of the surface in somewhat similar ways [2,6,7-9]. McKeeby et al. (2019) demonstrated observable changes in radiance and emissivity of both volcanic and non-volcanic topographic surfaces on Mars using two Thermal Emission Imaging System (THEMIS) data sets (nadir and off-nadir) acquired as part of a Routine Off-nadir Targeted Observation (ROTO) of the Mars Odyssey spacecraft. A difference map of these two emissivity images was created that highlights these spectral variations. They are interpreted to be due to subpixel, anisothermal mixing (shadowed + warm rock faces) caused by centimeter to meter scale surface roughness. The same difference image also showed variations in local emission angle due to large scale topographic changes (crater walls and volcanic flow fronts) with respect to the viewing angle. The degree of spectral change for each of these surfaces was also documented [9]. The work here expands upon that initial study.

Methods: TIR emissivity spectra were collected using a custom-created Miniature Multispectral Thermal Camera (MMT-Cam) [10]. This instrument has one open broadband port and six TIR wavelength bands in the 8 to 12 µm, covering similar regions to both the Earth-orbiting Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER) and the Mars-orbiting THEMIS instruments. Emissivity data were acquired with the MMT-Cam at nadir and 21° off-nadir viewing angles, a similar geometry to the THEMIS ROTO data. This was accomplished by measuring the tilt of the instrument relative to the sample surface (tilting the camera nadir and off-nadir). Samples were heated to 80°C prior to data acquisition to improve the signal to noise above that of the background. This configuration tests the spectral change with emission angle. Samples chosen represent both smooth and vesicated basalt as well as a sample of high-silica obsidian glass for comparison. The rough and smooth samples were collected in prior field campaigns from the Mauna Ulu flow field, Hawaii. The obsidian sample was obtained from Mono Domes, California. All samples are archive at the University of Pittsburgh Image Visualization and Infrared Vibrational (IVIS) laboratory archive.

Results: An obvious decrease in spectral contrast or increase in overall emissivity between the nadir and off-nadir measurements is seen, similar to that observed in the higher emission angle, off-nadir, THEMIS data (Figure 1) [9] and in laboratory emissivity data of surface roughness [11]. Changes in spectral features are also visible, particularly at the 9.5 and 10 µm band. Additionally, spectral slopes were also calculated. The negative slopes of the smooth and rough samples show little to no change between nadir and off nadir. The high silica glass spectrum shows a slight positive change in slope between nadir and off nadir, likely a function of the smooth, highly reflective glassy surface.

Discussion: Surface roughness and topographic slopes produce differences in TIR emission [1-6,9,11]. All samples were uniformly heated prior to analysis. This generally limits any potential anisothermal effects due to shadowing of the surface. Differences therefore are attributed to the emission angle. This limits the amount of spectral slope change, but can explain the observed decrease in spectral contrast [11]. A similar decrease in spectral contrast was observed in THEMIS ROTO data from the steep crater wall (Figure 1D) [9]. A slight negative change in slope is apparent between the nadir and off nadir THEMIS emissivity measurements. Although this surface appears smooth in HIRISE imagery, this surface may undergo a small degree of anisothermal diurnal heating detectable by TIR remote sensing.

Future Work: A custom built sample stage compatible with the MMT-CAM and a Nicolet 670 Fourier Transform infrared Spectrometer (FTIR) is currently under development. This will reduce potential measurement inaccuracies by allowing the sample to rotate around a central plane instead of relying on movement of the camera. Samples with greater variance in degrees of roughness will be used to better simulate the effects of subpixel anisothermality seen in the THEMIS ROTO data of the Arisa Mons lava flows.

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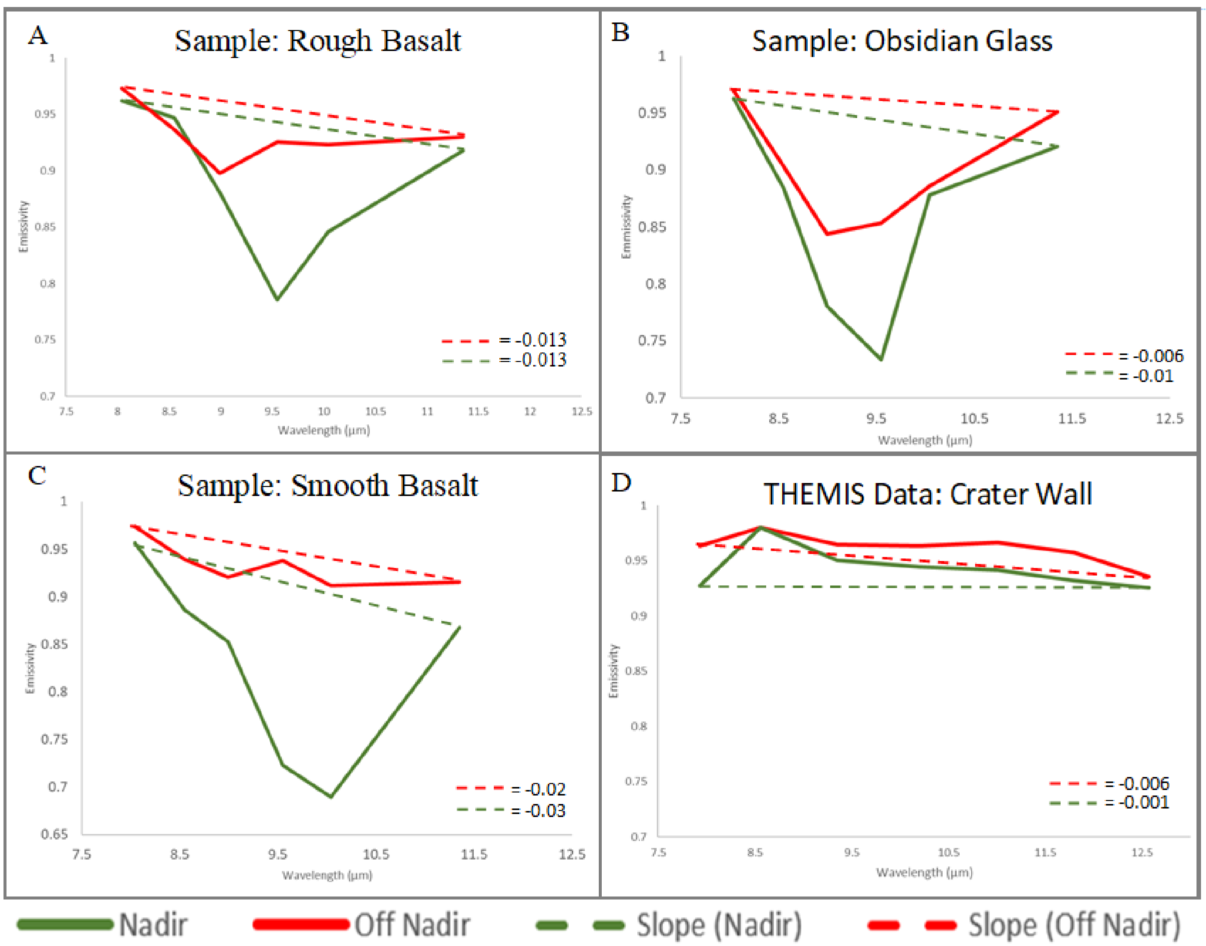

Figure 1. (A-C) TIR Emissivity spectra from the MMT-Cam comparing rough and smooth basaltic surfaces to high-silica glass. Spectra were collected at two viewing angles: nadir (green) at 90° and off nadir (red) at 21°. Spectral slopes (dashed) were calculated for each spectrum. The slopes of both basaltic samples are quite similar, whereas the differences are more pronounced for the obsidian glass sample. (D) THEMIS ROTO emissivity data (bands 3-9) from a steep crater wall in Arsia Mons (THEMIS ID #I68222002). A decrease in spectral contrast and slightly negative change in spectral slope can be observed between the nadir and off nadir measurements